13633

Way

NIC #13633
Packet Radio Temporary Note #8

Network Analysis Corporation
29 January 1973

PACKET DATA COMMUNICATION ON CATV SYSTEMS

Although local data distribution systems will be subjected to a wide variety of traffic requirements, in general it appears there will be a large number of users with low average traffic but high peak demands. This is ideal for packet communication with an ALOHA random access multiplex channel [Abramson, 1970; Roberts, 1972]. To meet this need for local distribution of data, ARPA has suggested an over-the-air packet radio transmission system [Packet Radio Temporary Note 5; 1973] which can operate in hostile environments and with mobile terminals. However, in urban areas there are two difficulties with radio transmission:

1) Because of multipath interference arising from reflections off buildings, the channel capacity of a broadcast link is limited to about 100 Kbits/sec.

2) Stations can hear far more traffic than they can handle when terminals broadcast with a range suitable for rural as well as urban areas.

Both these problems can be avoided while still retaining the main idea of using ALOHA random access multiplexing; instead of operating in an over-the-air broadcast transmission mode, data can be sent over the existing wideband facilities of cable television systems. Recent FCC rulings require that all new CATV systems have two way capability. Penetrations of 40-60% of U.S. homes is projected by the end of the decade [Sloan, 1971]. Moreover, most of the major new office buildings will have wide-band communication channels built in. For example, in the New York World Trade Center, there is a system of switched wideband communication channels. The user can select 60 KHz audio channels or 15 MHz video channels and has an individual wideband cable connection to the central switch [Friedlander, 1972]. By 1980" the wired city" will be close to reality.

The purpose of this note is to investigate the technical feasibility of ALOHA Random Access packet transmission over a video channel on a coaxial cable of a standard CATV system. We have not examined the detailed design of such a system but rather the gross parameters which determine the limits of system performance and hardware specifications. We have been conservative in assigning values to these parameters.

The conclusion of the study is that typical CATV systems which meet existing specifications for video transmission can support any reasonable data requirements with response times and error rates that are considered superior by any communications standards. For example, at an average input rate of 40 bits/sec per terminal (see Packet Radio Temporary Note 5) with signal to noise ratio degraded by 20db a single trunk operating in a slotted ALOHA mode, 100Kbit/sec. can handle 900 active terminals at a bit error rate of better than 10^{-22}. At 1 Megabit/sec. the same system can handle 9,000 active terminals.

The critical point at which the ALOHA mode uses less bandwidth than frequency or time division multiplexing is when the fraction of time a terminal is transmitting is less than 1/2e for an unslotted system [Abramson, 1971]. Thus, if each terminal transmitting for 5 seconds per hour the ALOHA system can handle 130 times as many terminals for the same bandwidth used as a standard TDM or FDM channel.

One major question has not been addressed in detail in this report and is to be considered next; can packet communication in CATV systems be made conveniently compatible with the

proposed ARPA Packet System which operates in the broadcast mode. Three problems which must be considered are:

1) The useable channel capacity of a Tv channel is an order of magnitude greater than that available on a radio channel.

2) It is highly unlikely that the broadcast system will use the VHF or SUB-VHF channels available in CATV so that frequency conversions will be necessary.

3) The terminal interface to the cable must be different from that used for radio transmission.

Digitized by the Internet Archive
in 2025 with funding from
Amateur Radio Digital Communications, Grant 151

https://archive.org/details/temporary-note-008

CATV System Description

Cable Television (CATV) systems in the U.S.A. are almost universally tree structured networks of co-axial cables installed for the distribution of broadcast type television signals from a master television receiving antenna to home type television receivers. Multiple television signals, which may be received at a central site or relayed over long distances by microwave systems, are processed at a central "head end" and frequency division multiplexed onto co-axial cable for distribution. Co-axial cables now in use are universally 75 ohm impedance types, usually of seamless aluminum sheathed construction, foam polyethylene dielectric, and solid copper or copper clad aluminum center conductor. The co-axial cables range in size from 3/4 inch outer diameter for "main trunk cables," through 1/2 inch size down to a .412 inch size for "local distribution." The service drop lines are usually flexible cables of about 1/4 inch diameter. The useful frequency range includes the VHF television band, 54-216 MHz, and broadband transistorized amplifiers are installed with equalizers to compensate for cable losses. Practical systems are alligned to be unity gain networks with amplifiers spaced about 20 dB at the highest transmitted frequency.

Cable losses range from about 1 dB/100' at 220 MHz for the 3/4 inch size cable to about 5 dB/100' for the flexible service drop cables. Power division at cable splits, and "taps" into subscribers' homes are accomplished through hybrid and directional couplers. All system components are carefully matched to 75 ohms to minimize internal signal reflections within the system.

System amplifiers are subject to rigorous linearity specifications. Amplifier overloads manifest themselves as cross modulations between channels and as undesired second and third order intermodulation and harmonic products. Amplifier operating levels are bounded on the lower side by system signal to noise ratio objectives which are about 40 dB for reasonable acceptable performance as a television distribution system. A typical system will have amplifier inputs at about +10 dBmv and maximum output at about +30 dBmv. System operating levels are rigorously controlled by pilot carriers and thermal compensation systems.

More recent cable systems have been built using a "hub" principal in which tree-structured networks originate from a number of "hubs" throughout the community serviced (See Fig. 1). The "hubs" may contain equipment for more elaborate control of

signal levels and it may be possible to perform some special switching functions such as the interconnection of sub-trunks for special purposes.

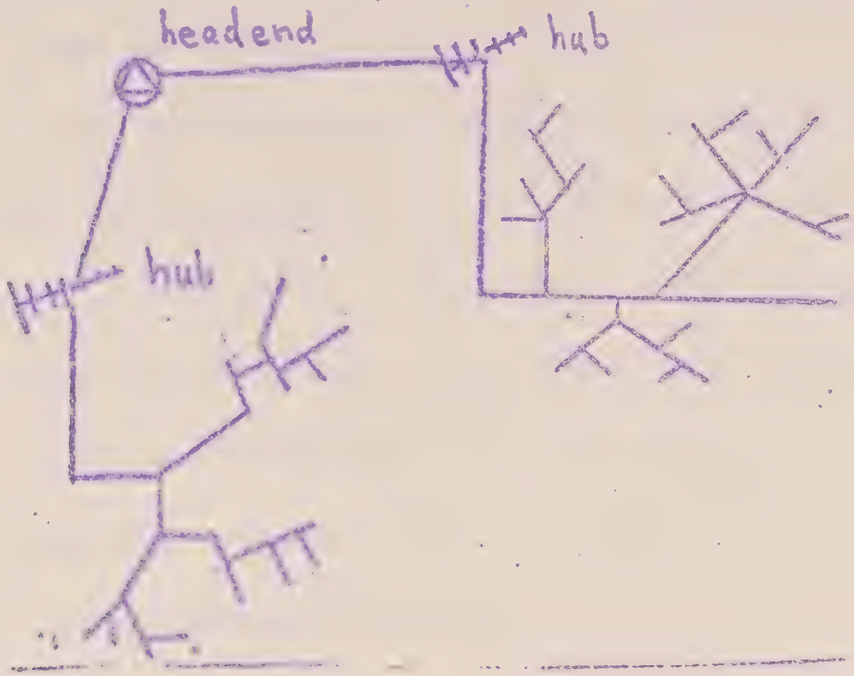


FIGURE 1
HUB SYSTEM

Two-Way CATV Configurations

FCC regulations now require that new CATV systems must have two-way capability. Practically speaking, this does not mean that all new systems are two-way systems, but rather that amplifier units are installed with forward amplifiers modules in place and with distances between amplifiers constrained so that at some future date reverse amplifier modules can be installed for two-way operation. However, a number of actual fully two-way systems are presently being built and

the number is increasing rapidly. Most present two way systems use the configuration in Figure 2. Filters at each end of the station separate low (L) and high (H) frequencies and direct them to amplifiers usually referred to as "downstream" from the head end and "upstream" toward the head end.

A number of possible "two-way" configurations are shown in Figures 2, 3, and 4 [Jerrold, 1971]. The final choice between single cable/two-way, multi-cable/two-way, and multi-cable without two-way filters will probably be made on the basis of video transmission requirements.

There are no Government regulations as to minimum specification for a system. Hence we will base our discussion on the characteristics of a representative two-way system, the Boston complex. This system is being built in about 10 stages, one of which is already installed and the final phase of which is to be completed within a year. At its completion Boston will be one of the largest systems in existence in the U.S. The Boston System uses the "feederbacker" configuration shown in Figure 4 with the frequencies assigned to the upstream and downstream paths specifically indicated.

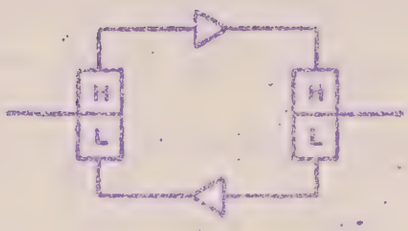


Figure 2

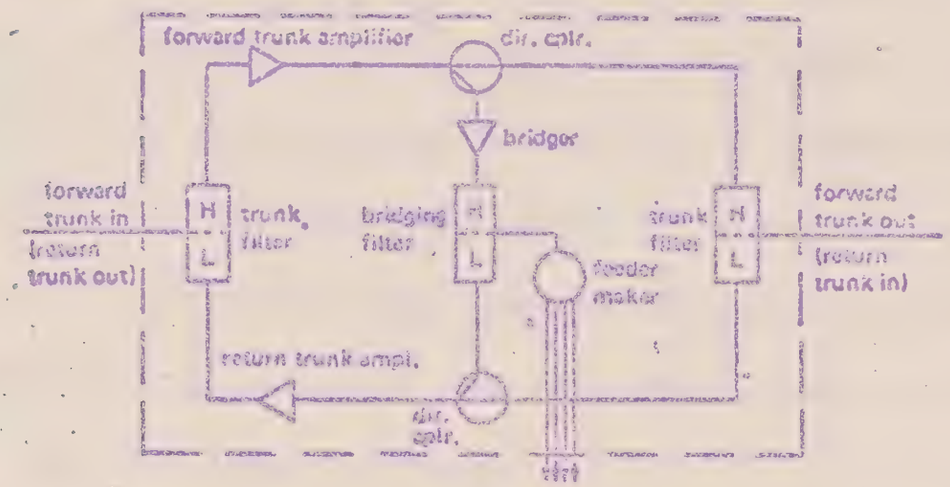


Figure 3 Two-way CATV Repeater (with feeders).

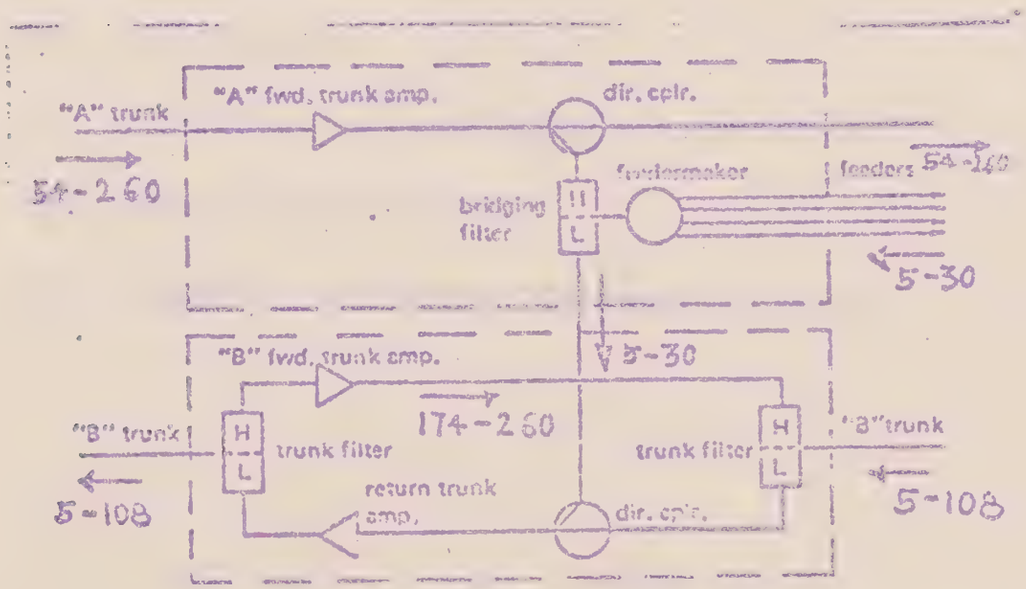


Figure 4 Dual Trunk/Single Feeder Station (Boston Configuration)

Design of an ALOHA Packet Data System for the Boston CATV System

We shall see that CATV systems are highly linear by almost any communication engineering standard and the enormous bandwidth of a system designed to carry 20 TV channels or more with high quality will probably stand additional data loading with little strain. Almost any data transmission scheme could be used provided that it is modulated onto an RF carrier passed by the system and that modulators can be obtained at reasonable costs to transmit at the required data rates. Loading characteristics would probably be similar to loading expected in conventional carrier technology. To show the technical feasibility of an ALOHA type packat transmission scheme on a CATV system we will consider the following items in order:

A) Available Spectrum

B) Data Rates and Error Probabilities

C) Intersymbol Interference

D) Reliability

E) Interference from Power Frequencies

F) Number of terminals

G) Converter Cost for Data transmission

A. Available Spectrum

Data transmission on CATV systems will generally have to be fitted into space not being used for TV channels or for pilot frequencies. Hence, it is best to first describe the frequency allocation for video signals. TV channels are allocated six Megahertz bandwidths. Broadcasted TV channels are in the LO-VHF range 54MHz-88MHz, the Hi-VHF range 174 MHz - 216 MHz and the UHF range 470 MHz - 890 MHz. The TV frequency allocations on cable are different. They partition the 54-300 MH spectrum as follows:

Sub-VHF 5-54 MHz

LO-VHF 54-88 MHz

Mid-band 88-174 MHz

Hi-VHF 174-216 MHz

Super-band 216-300 MHz

There is still discussion going on as to whether the mid-band should be used within a cable system because of danger of interference to aircraft navigation in case of signal leakage out of the cable. Data might be squeezed into bands not used by TV signals. Some space is available below Channel 2 at 48-54 MHz. The space between Channel 4

transmission going on so as to
within a cable system
out of the cable. Data might
signals. Some

and 5(72-76 MHz) might be used for low level data signals. High signal levels in this area could cause harmful picture interference on some TV sets.

A more likely situation is that two 6 MHz video channels--one upstream and one downstream--would be set aside for data transmission. The simple fact is that 21 to 30 channels are available on a single cable system and 42 to 60 channels on a dual cable system. These channels have not all yet been pre-empted by video transmission.

The next question is whether the cable spectrum is compatible with terminal devices built to communicate using radio waves at UHF frequencies. Proposals have been made to transmit UHF signals over cable. However, there is no immediate prospect of their fruition and UHF signals can certainly not be sent over existing systems with present amplifier spacings. For transmission over cable, UHF signals must therefore be converted to sub-UHF bands. For transmissions from the head and this poses no problems different from video UHF signals and is readily handled at the head end with a single efficient UHF to VHF frequency converter.

At the TV receiver the problem is more difficult for both video and packet data transmission and is somewhat different

for the two types of signal in the upstream direction. In the downstream direction the most likely immediate prospect is a frequency converter which converts the VHF signal back to UHF (tuner) or a frequency converter which allows one to switch either a real VHF signal or a real UHF channel onto a VHF TV output (block converter). A longer range possibility is the design of TV receivers which can handle 20 to 60 input channels. At any rate, in the downstream direction the frequency conversion problem is the same for video and data. In the upstream direction video signals are introduced, without conversion in the proper VHF channel. However, if the digital data is at a UHF frequency to be compatible with broadcast transmission, it must be downconverted.

B. Data Rates and Error Probabilities

Most two-way systems are being developed with an upstream channel designed to permit input from virtually any location in the network. The result is a large number of noise sources being fed upstream toward a common source. Individual cable television amplifiers usually have a noise figure of about 10db for a 6 MHz channel. Cascading amplifiers can increase effective system noise figure by 30db or more. Nevertheless,

...types of signal in the upstream direction. ...
...can direction the most likely immediate progr...
...converter to convert the VHF signal back ...
...type ... or a frequency converter which allows one to ...
...a real VHF channel to a real VHF channel ...
...VF equipment (block conversion). A longer range ...
...ion of VF receivers which can handle 2Q to 60 ...
...ot any rate, in the downstream direction. ...
...ion is ... for video and data, ...
...tion video signals are introduced, without ...
...the proper VHF channel. However, if the ...
...the frequency to be compatible with ...
...conversion, it must be downconverted.

...ne Error Pr... ...ties

...two-way systems are being developed with/... ...
channel limited to permit input from virtually any ...
in the system. The result is a large number of noise ...
being fed ...ifiers toward a common source. Individual ...
relaxation amplifiers usually have a noise figure of ...
10db for a 6 MHz channel. Cascading amplifiers can increase ...
effective system noise figure by 30db or more. Transmission,

we shall see that system specifications on signal-to-noise ratio for CATV systems are stringent enough so that packets can be sent with existing analog repeaters, and no digital repeaters, such that bit rate error probabilities are negligible.

For example, in Boston the worst signal-to-thermal noise ratio is limited to 43db and the worst cross modulation to signal ratio is limited to -47 db. System operators may want to limit data channel carriers to a level of 10 to 20 db below TV operating levels in order to minimize additional loading due to the data channel carriers. [Switzer, 1972]. The cable operator, at least for the time being, is making his living by providing a maximum number of downstream television channels and will accept data channels only on a non-interfering basis.

Accepting these restrictions, in the worst case, we would be limited to 23 db signal to thermal noise ratio and -27 db cross modulation to signal ratio. Let us consider both of these sets of restrictions to determine the resulting CATV system performance for random access packet transmission. In particular, we will investigate the maximum data rates and the resulting error probabilities.

For the sake of illustration we will consider noncoherent frequency shift keying (FSK). The error rates for coherent detection or phase shift keying, of course, would be even lower [Schwartz et al., 1966]

Let S = Signal power

N = Noise power

N_c = Cross modulation noise power

N_r = Thermal noise power

t = Average synchronization error time

T = Bit width time

Then the signal to noise ratio is

$$\frac{S}{N} = \frac{Sq}{N_c + N_r} = \frac{q}{(N_c/S)+(N_r/S)}$$

where

$$q = \left(1 - \frac{2t}{T}\right)^2$$

Let Pe be the bit rate error probability

Let m be the number of keying frequencies in a multiple FSK System. Then [Schwartz et al, 1966] [Bell Tel.Lab.,1971]

$$Pe = \frac{m-1}{m} e^{\frac{-(S/N)}{2(m-1)}}$$

For the sake of illustration we will consider now [illegible] [illegible] shift keying [illegible]. The error rates for [illegible] [illegible] phase shift keying, of course, would [illegible] [illegible] et al [illegible]

Let S = Signal power

N = Noise power

N_c = Cross modulation noise power

N_r = Thermal noise [illegible]

t = Average synchronization error time

T = Bit [illegible] time

Then the signal to noise ratio is

$$\frac{S}{N} = \frac{[illegible]}{N_c + N_r} \quad \frac{[illegible]}{(N_c/S) + (N_r/S)}$$

where

$$q = (1 - \frac{[illegible]}{[illegible]})^2$$

Let Pe be the bit rate error probability

Let [illegible] be the number of keying frequencies in a multiple [illegible] system. Then (Schwartz et al. 1966) [Bell Tel.Lab.,1971]

$$Pe = \frac{[illegible]}{[illegible]} e^{\frac{-(S/N)}{2(m-1)}}$$

We assume that each packet carries its own synchronizing bit and hence there is no need to synchronize every terminal to a master clock. Therefore, temperature, pressure and humidity variations which have approximately the same effects at all frequencies do not enter into the calculation of t. The group delay variation over a six Megahertz bandwidth is less than .2 μ seconds [Rogeness, 1972]. For a 1 Megabit pulse rate T = 1 μ sec. and t = .2 μ sec. Hence q = .36. Using these formulas and numbers we have the error probabilities in Table 1 for the Boston complex.

TABLE 1
ERROR RATES FOR FSK

System Label	Type of Specification	(N_o/S)	(S/N_o)	m	Pe
A	Boston Specs.	-47db	43db	2	$1/2\, e^{-5,148} \approx 1/2 \times 10^{-2,239}$
B	Boston Specs.	-47db	43db	4	$3/4\, e^{-571} \approx 3/4 \times 10^{-248}$
C	Boston Specs.	-47db	43db	8	$7/8\, e^{-104} \approx 7/8 \times 10^{-45}$
D	Boston Specs. - degraded by 20db	-27db	23db	2	$1/2\, e^{-51} \approx .5 \times 10^{-22}$

TABLE I

ERROR RATES FOR PSK

A	Boston Space.	-47db	43db	2
B	Boston Space.	-47db	43db	4
C	Boston Space.	-47db	43db	8
D	Boston Space. - degraded by 20db	-27db	23db	2

It is well known that for effective signal to noise ratios above 20db there is a threshhold effect for error probabilities. This is born out by the negligible error rates in Table 1. Even for the degraded specifications the error rate is low enough for the most stringent practical data requirements.

At a rate of 10^6 pulses/second the PSK signal will occupy the 6MHz bandwidth [Switzer, 1972] with negligible intermodulation into TV channels [Schwartz et al., 1966].

C. Intersymbol Interference

The signal levels in a CATV system are rigorously controlled via AGC and dual pilot carriers. Ripples are kept to less than 1db over the whole frequency band. In any case, frequency shift keying is insensitive to small amplitude variations. The effect of group delay error has already been taken into account in the use of q in the formula for error probability. The remaining source of intersymbol interference is the reflection of pulses and the effect of the reflected pulses on the transmitted data.

There are three types of disturbances due to reflections. In each case we shall see that video restrictions are certainly stringent enough to avoid any difficulties for data transmission.

1) Periodic changes of minute magnitude uniformly distributed along the cable length, the magnitude of changes being essentially equal from period to period due to the nature of the manufacturing process, cause reflections which add in phase at certain frequencies. The signal strength relationship of the reflected wave to the incident wave is referred to as structural return loss (SRL). Typical values for the magnitude of SRL are better than -26db. [Olszewski and Lubars, 1970].

Assuming that the reflected signal is always of an opposite sign to the original signal, the signal level is degraded by at most S-a where a is the amplitude of the reflected signal. The signal to noise ratio becomes [BTL, 1971]

$$\frac{S-a}{N} = \frac{S}{N}\left(1-\frac{a}{S}\right)$$

In other words $\frac{S}{N}$ is degraded by $\left(1-\frac{a}{S}\right)$

For a reflected signal of -26db $\left(1-\frac{a}{S}\right)$ is .9975. Hence the reflection problem is completely under control.

2) A localised change or changes on the cable cause echo phenomena. Low reflection coefficients of active and passive devices and the use of directional couplers at all subscriber taps ensure that the magnitudes of reflected pulses are in the "no ghost range" of Figure 5. [Rheinfelder, 1970; Shekel, 1962; Mertz, 1953]. These are translated into critical distances for different types of cable in Figure 6. Thus, for example, considering the reflection on .412 inch cable at Channel 13 the critical distance is about 250 feet and the ratio of the magnitude of the reflected signal to the magnitude of the original signal is -23db.

3) Randomly distributed changes of random magnitude which persist throughout the cable length cause reflections which do not add in phase. These can be taken into account in noise calculations and are usually negligible.

D. Reliability

Data users will find cable system reliability quite poor when compared with common carrier facilities that they are used to. One of the major problems with data transmission on a CATV system is that there is virtually no redundancy in cable systems. Most present systems do not even have standby primary power. Alternate routings are not available in case of system "catastrophe."

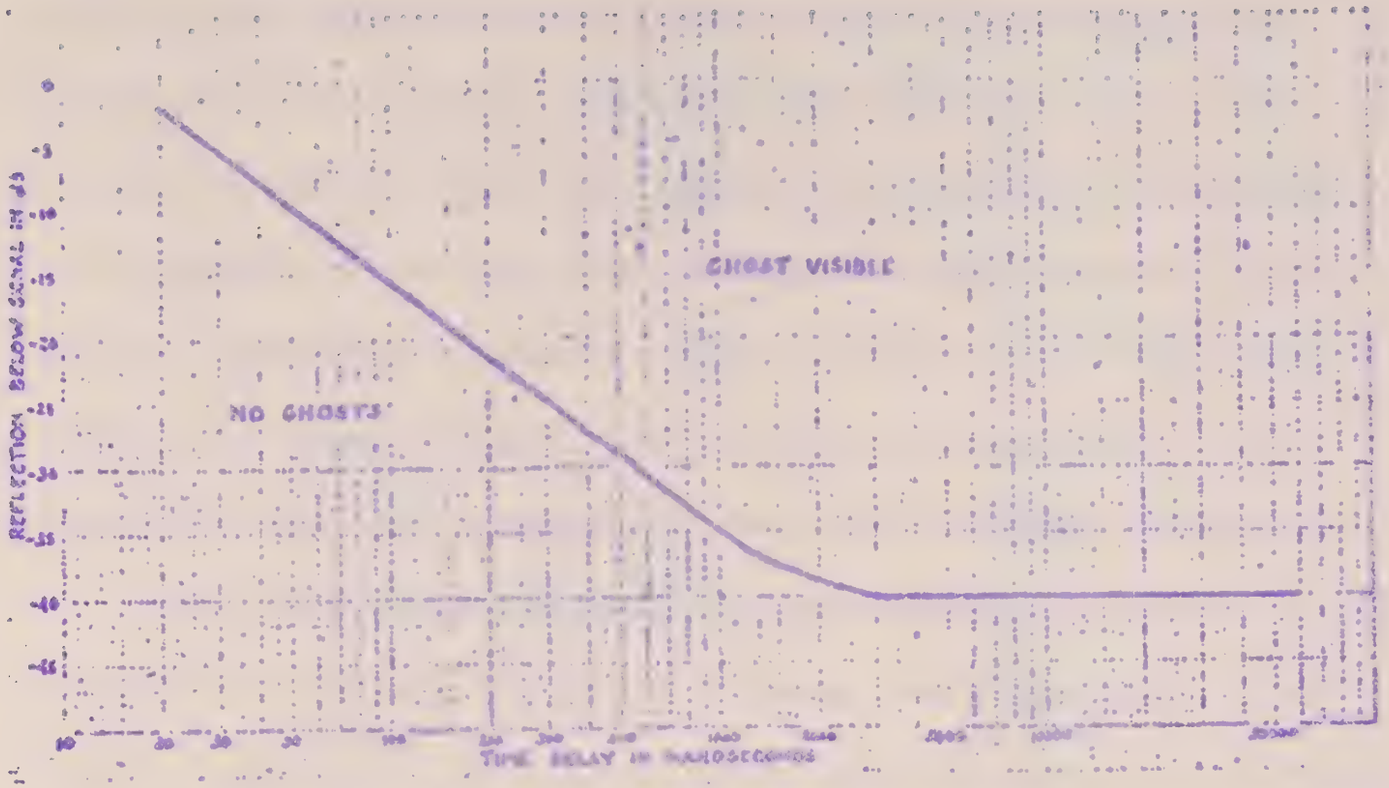


Fig. 5 Curve showing perceptibility of ghosts.

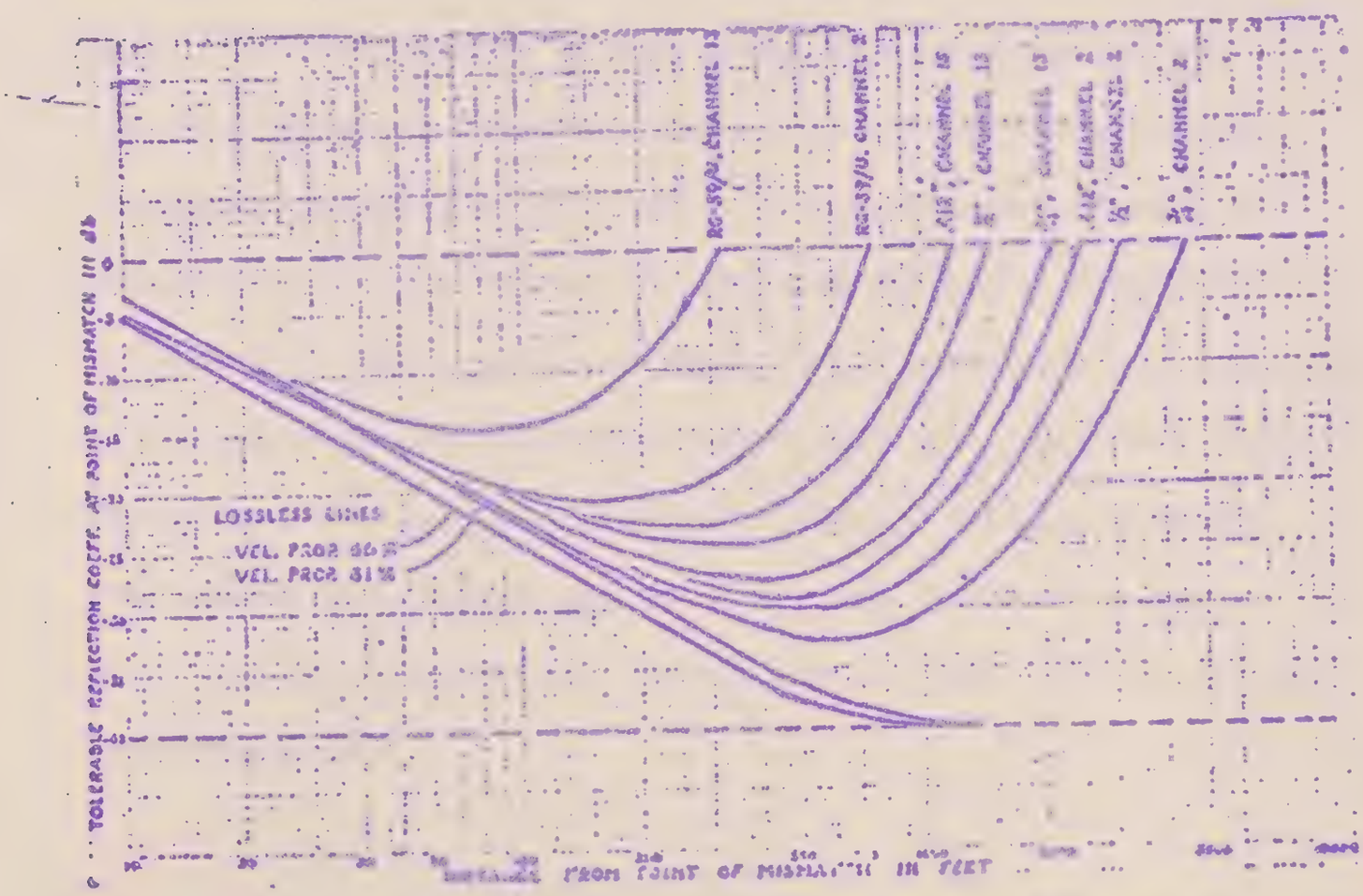
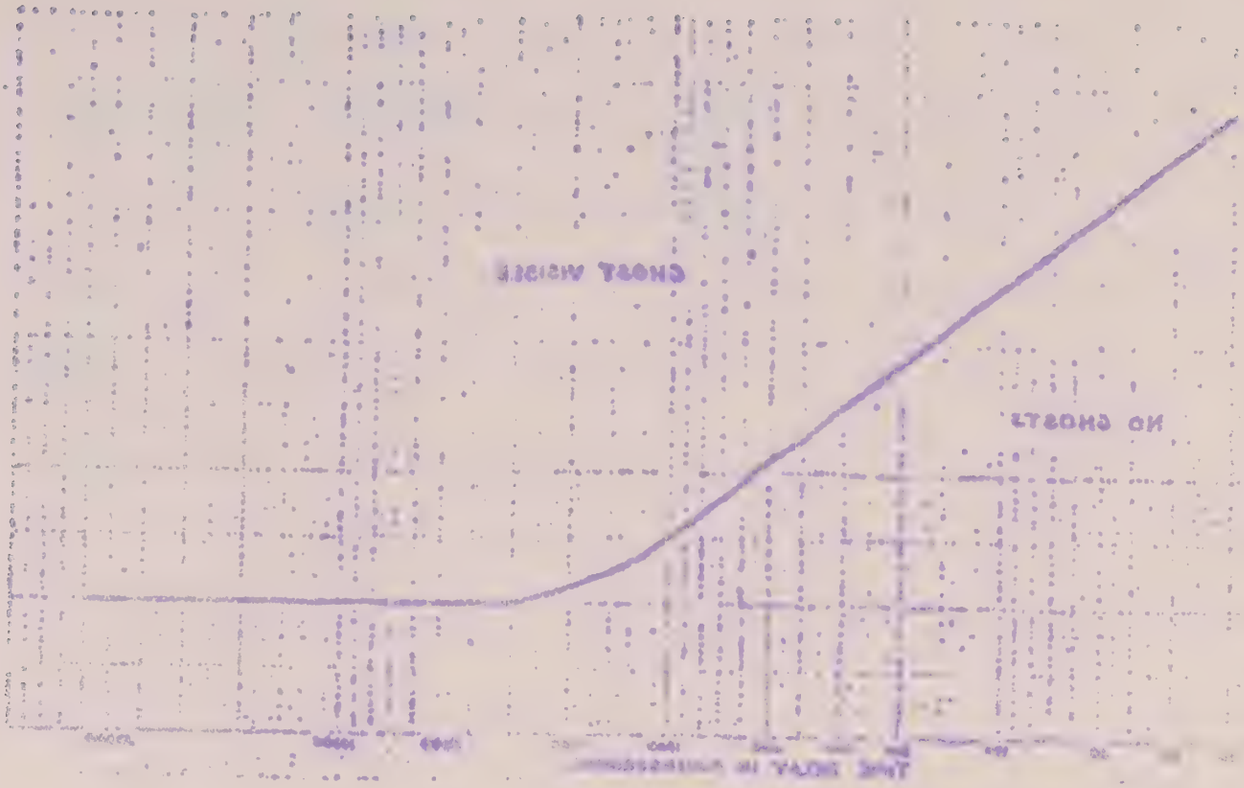
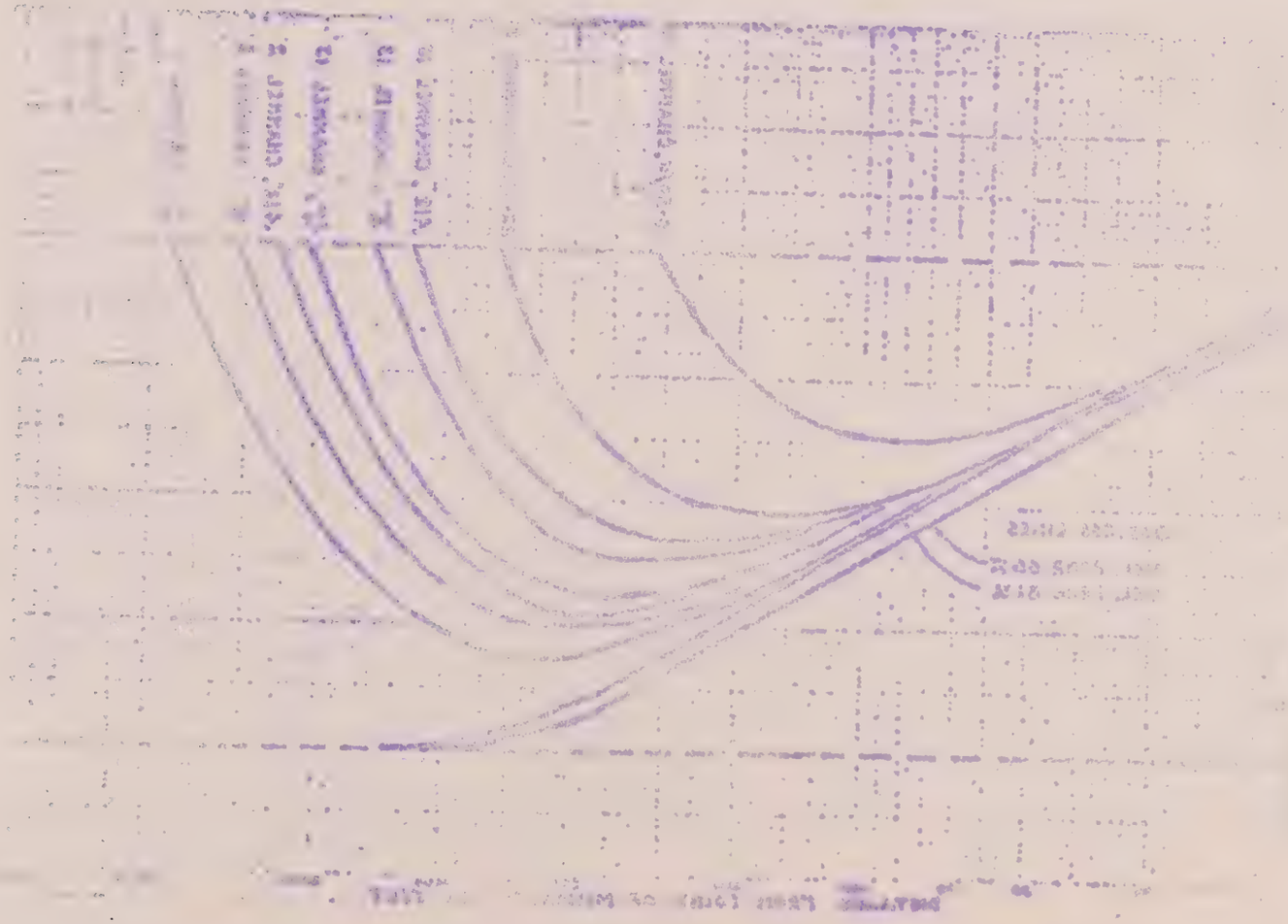


Fig. 6 Graph for determination of critical cable lengths.


GHOST NOISE
NO GHOSTS



There are no Government or industry minimal standards for acceptable performance; hence, performance will vary from system to system. Many old systems were built to extremely loose specifications on noise and cross modulation and have serious reflection problems because of the use of unmatched subscriber taps. Fortunately, systems in large cities are much newer and are required to meet more exacting standards.

Even with these systems, the construction norms are still those which satisfy casual TV viewers, not data users. Thus loose connections and cracked cable sheaths cause intermittant transmission conditions, and momentary "disconnect". These would cause only minor "flashes" on a TV picture but constitute major data dropouts in a high speed data circuit. Cable connections often loosen under influence of vibration and the cold-flow property of aluminum. Strong RF sources such as nearby mobile radio transmitters, amateur radio transmitters, AM and short wave broadcasting stations leak into both upstream and downstream cables and interfere with the low level television and data signals [Switzer, 1972]. Finally systems are tested haphazardly and hence in some parts of a system noise and cross modulation levels may not meet written system specifications.

E. Interference from Power Frequencies

Cable system amplifiers are powered by low voltage 60 Hz power through the co-axial cable. This power may be as high as 60 volts (RMS) and currents may run to 10 amperes (RMS) with peak currents even higher. There are significant harmonics of the power line frequencies present. Some amplifiers use switching mode power supplies with switching frequencies in the 10-20 KHz range. Hash from these switching regulators also finds its way into the cable. However, both the 60 cycle harmonics and hash limit only the area of very low frequencies which are generally avoided for data transmission anyway.

F. Number of Terminals

In a CATV System there are separate channels allocated for upstream and downstream messages. Since the responses are longer and more frequent than the inquiries, they will limit the number of terminals.

For integers w, x, y, z, let

$450\ w$ = packet size, (no. of bits/packet)

$2x$ = rate of messages, (no. of responses/hr.)

$4y$ = message size, (number of packets/response)

$.1 \times 10^{-6} z$ = pulse duration, seconds

At a 1 Megabit/sec. rate $z = 1$ and the pulse duration is 1 μsec on a binary system.

Interference from Power Frequencies

Cable system amplifiers are powered by low voltage d.c. power through the co-axial cable. This power may be as high as 60 volts (RMS) and currents may run to 10 amperes (RMS) with [illegible] currents and [illegible]. These are significant [illegible] of the power line frequencies present. Some amplifiers use switching mode power supplies with switching frequencies in the 10-[illegible] [illegible]. Hash from these switching regulators also [illegible] its way into the cable. However, both the 60 cycle harmonics and hash limit only the use of very low frequencies which are generally avoided for data transmission anyway.

Number of Terminals

In a CATV System there are separate channels allocated for upstream and downstream messages. Since the responses are longer and more frequent than the inquiries, they will limit the number of terminals.

For integers w, x, y, z, let

$4\pi w$ = packet size, (no. of bits/packet)

$2x$ = rate of messages/(no. of responses/hr.)

$4y$ = message size, (number of packets/response)

$1 \times 10^{-6} z$ = pulse duration, seconds

At a 1 Megabit/sec. rate $z = 1$ and the pulse duration is 1 μsec on a binary system.

Note that the number of bits/second is

$$\frac{450w \cdot 2x \cdot 4y}{3600} = wxy \text{ which we define as } \Omega.$$

Then the number of packets/second for each terminal is

$$\lambda = \frac{8xy}{3600}$$

At a 3 Megabit/sec rate the pulse duration is .33 μseconds. The corresponding average packet duration is

$$\tau = zw\ 450 \times 10^{-6} \text{ seconds}$$

The maximum number of active users per trunk in a system is given by [Abramson, 1970]

$$k_{max_u} = \frac{1}{2e\lambda\tau} \text{ for an unslotted system}$$

and

$$k_{max_s} = \frac{1}{e\lambda\tau} \text{ for a slotted system.}$$

In other words the bandwidth of an ALOHA type interactive channel is effectively reduced by a factor of 2e for an unslotted system and a factor of e for a slotted slotted system.

Hence

$$k_{max_u} = \frac{3600 \times 10^6}{2e \cdot 3600\ wxyz}$$

$$= \frac{.184 \times 10^6}{\Omega z}$$

Similarly

$$k_{max_s} = \frac{.368 \times 10^6}{\Omega z}$$

Note that the number of bits/second is

$$\frac{4800 \cdot 2x \cdot 4y}{3600} = \text{very nearly we define as } \gamma:$$

the number of packets/second the ends terminal is

$$\gamma = \frac{8xy}{3600}$$

As a 3 Megabit/sec rate the pu... transmission is ...y

the corresponding average pa... duration is

$$\tau = xy\ 450 \times 10^{-6} \text{ seconds}$$

the maximum number of active ... per trunk in a ...

(Abramson, 1971)

$$K_{max} = \frac{\ldots}{\ldots}$$ for the unslotted Aloha

$$K_{max} = \frac{\ldots}{\ldots}$$ slotted Aloha

... where we use the ... of an ALOHA ty... (approximately)

... effectively reduced by ... factor of 2e for an unslotted ...

... number of ... slotted Aloha ...

$$\ldots$$

$$\ldots$$

$$\ldots$$

Finally, in Figure 7 we plot the maximum number of active terminals for the systems in Table 1. The curves labeled A, B, C and D correspond to the slotted systems in Table 1 labeled A, B, C and D. The lines labeled A', B', C' and D' are for the corresponding unslotted systems.

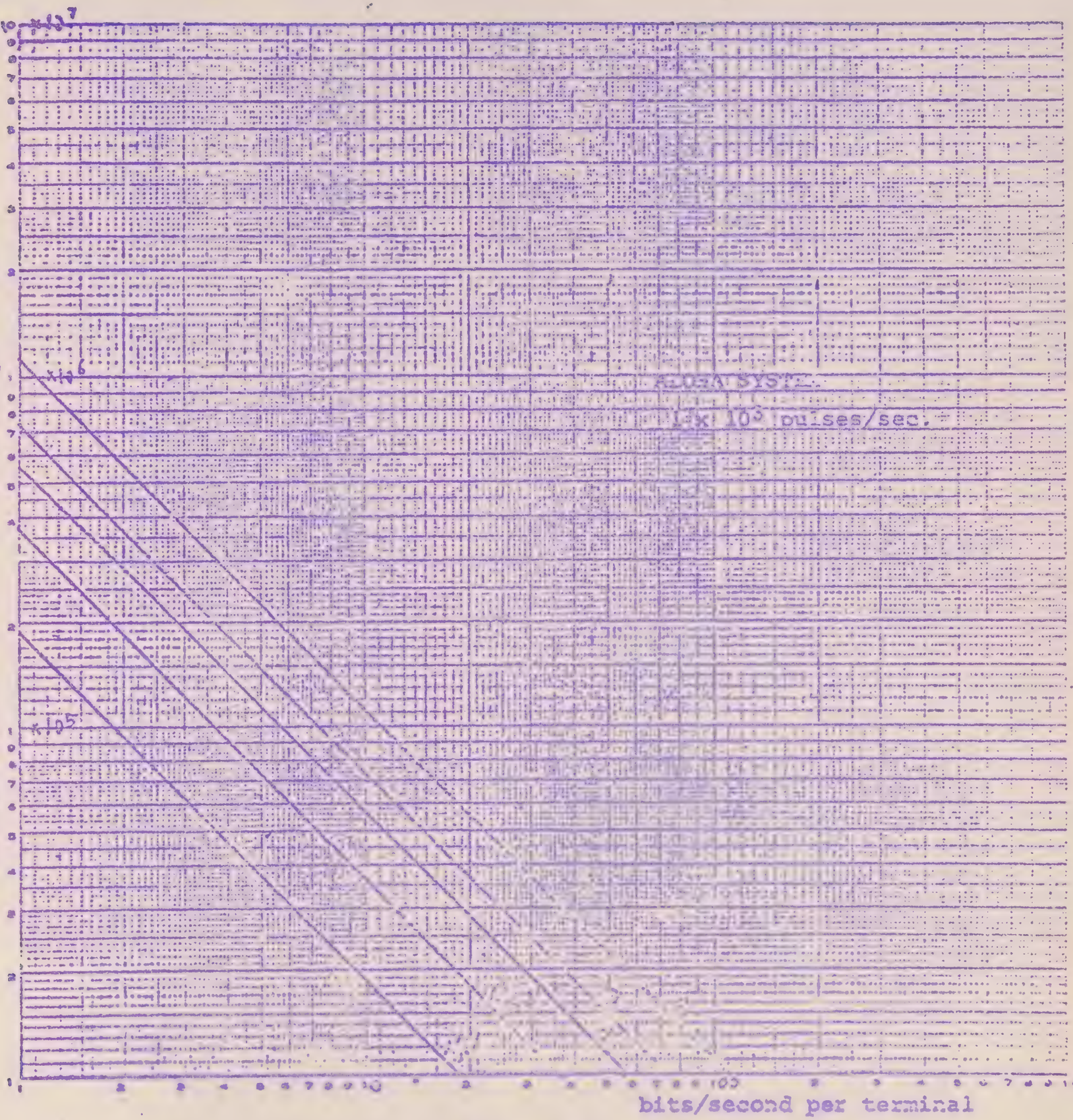
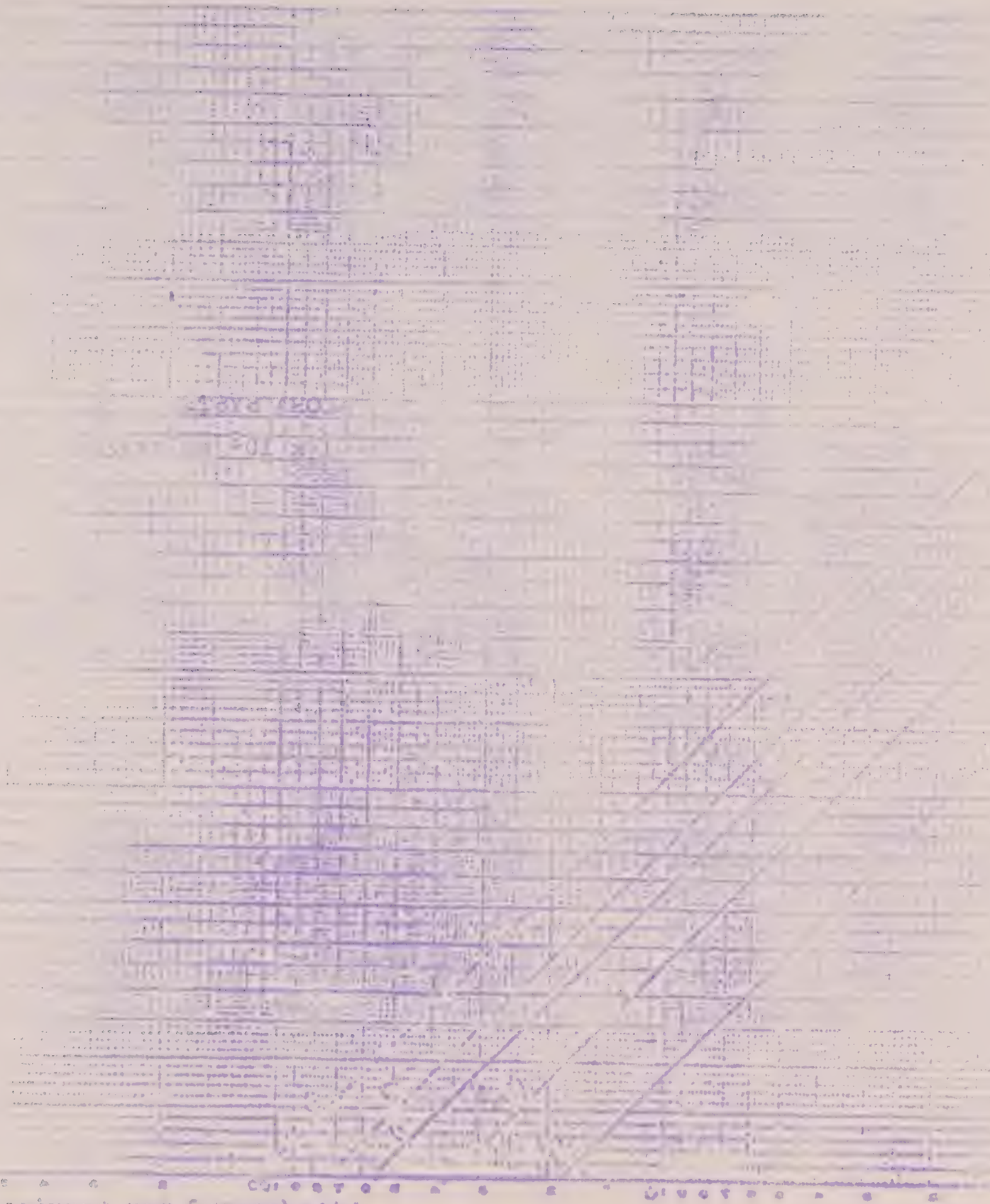


FIGURE 7

NUMBER OF TERMINALS PER TRUNK VS. BITS/SEC. PER TERMINAL



C. Converter Cost for Data Transmission

Once a two-way CATV system is installed the additional cost to be able to handle interactive packet data appears minimal. With an ALOHA type of random access packet technology no switching is necessary and the calculated data rates and error probabilities indicate that concentrators and digital repeaters will probably not be required.

An additional cost will be required for more rigid testing of systems to ensure that specifications are met. This might cost about $10.00 per subscriber. Assuming converters will be used to convert from UHF to VHF for upstream transmission, these introduce some uncertainty into the cost calculation. Quoting from the SLOAN Commission Report on CATV [Ward, 1971]

> "Present 25-channel tuner-converter costs are quoted in the range from $30 to $50 depending on the type and manufacturer. Actually, converter technology is in a period of transition. Only a few tens of thousands of converters of all types are yet in use, and although many of these have been cleverly devised from available VHF-TV tuner components which are standard, highly tooled production items, and thus reliable and low in cost, they do not represent an optimum solution to the interchannel interference problems in augmented-channel systems, or to further expansion of channel capacity. The industry is now moving toward new all-channel designs which can take full advantage of interference rejection possibilities ...and the new extensions in cable bandwidth (to 300 MHz). Until large-scale production builds up over the next few years, such new designs will undoubtedly cost more than present 25-channel designs, perhaps in the $50-60 region."

The additional cost of the transmitting device is, of course not included in the cost estimate.

Computer Chat for Data Transmission

Once a two-way CATV system is installed the additional cost
to be able to handle interactive packet data appears minimal.
No AM/FM type of random access packet technology is
necessary and the calculated data rates and error
probabilities indicate that concentrators and digital equipment
probably not be required.

An additional cost will be required for more
powerful computers to answer their specific needs. While active
users could pay $10/00 per subscriber, existing computer
systems could convert from UHF to VHF for
less than $1000 each. Assuming uncertainty into the
future Consultation Report for CATV Trend, 1979)
```
                                                    from $10
                                                    Actual
                                                    question.
                                                    of all types are
                                                    always carried
                                                    which are
                                                    any that is
                                                    of choice by the
                                                    capacity in cable
                                                    the energy will
                                                    addition by the
```

Conclusion

We can now examine Figure 7 to determine system performance under some typical data transmission requirements. We shall see that the performance is excellent and easily compatible with the structure of a typical CATV system. For a data rate of 40 bits/second per terminal, a single trunk can handle 9000 terminals with a slotted ALOHA system with an error rate of 10^{-22} at a signal to noise ratio degraded by 20 db. The average number of TV sets per trunk in Boston is approximately 27,000. Hence, the simplest modulation scheme will handle one third of all terminals in Boston as active terminals.

Conclusion

We can now examine Figure 7 to determine system performance under some typical data transmission requirements. We shall see that the performance is excellent and easily compatible with the structure of a typical CATV system. For a data rate of 40 bits/second per terminal, a single trunk can handle 9000 terminals with a slotted ALOHA system with an error rate of 10^{-22} at a signal to noise ratio degraded by 20 db. The average number of TV sets per trunk in Boston is approximately 27,000. Hence, the simplest modulation scheme will handle one third of all terminals in Boston as active terminals.

REFERENCES

1. N. Abramson, "The ALOHA System--Another Alternative for Computer Communications", AFIPS Conference Proceedings, Vol. 37, November, 1970, pp. 281-285

2. Bell Telephone Laboratories, "Transmission Systems for Communications," 1971

3. G. D. Friedlander, "Super Communications for World Traders" IEEE Spectrum, March 1972, pp. 74-83

4. Jerrold Electronics Corp. 1971 National Cable Television Convention Publicity Release on Two-Way Systems.

5. P. Mertz, "Influence of Echoes on TV Transmission", Journal of the SMPTE, May, 1953

6. J. A. Olszewski and H. Lubars, "Structural Return Loss Phenomenon in Coaxial Cables, "Proceedings of the IEEE, Vol. 58, No. 7, July 1970, pp. 1036-1050

7. Packet Radio Temporary Note 5, Packet Radio--System Considerations, NAC, January 1, 1973

8. W. A. Rheinfelder, "CATV System Engineering", TAB Books, Blue Ridge Summit, Pa., 1970

9. L. G. Roberts, "Extensions of Packet Communication Technology to a Hand Held Personal Terminal", Spring Joint Computer Conference, Atlantic City, May 16, 1972, pp. 295-303

10. G. Rogeness, "Contributing Sources and Magnitudes of Envelope Delay in Cable Transmission System Components", Official Transcript 21st Annual National Cable Television Association Convention, Chicago, May 14-17, 1972.

11. M. Schwartz, W. R. Bennett and S. Stein, "Communication Systems and Techniques", McGraw-Hill, 1966.

12. J. Shekel, "CATV Reflections", TV Horizons, April, 1962

13. Sloan Commission Report on Cable Communications, "On the Cable: The Television of Abundance", McGraw-Hill, 1971

14. I. Switzer, "The Cable System as a Computer Network", in Proc. Symp. Computer-Communications Networks and Teletraffic (Polytechnic Institute of Brooklyn, N.Y.), April 1972

15. J. E. Ward, "Present and Probable CATV/Broadband-Communication Technology", Report ESL-R-449, June 7, 1971, Revised Jan. 5, 1972. A report prepared for the Sloan Commission on Cable Communications.

REFERENCES

1. M. Abramson, "The ALOHA System--Another Alternative for Computer Communications", AFIPS Conference Proceedings, Vol. 37, November, 1970, pp. 281-285

2. Bell Telephone Laboratories, "Transmission Systems for Communications," 1971

3. G. D. Friedlander, "Super Communications for World Traders" IEEE Spectrum, March 1972, pp. 44-83

4. Jerrold Electronics Corp. 1971 National Cable Television Convention Publicity Release on Two-Way Systems.

5. P. Mertz, "Influence of Echoes on TV Transmission", Journal of the SMPTE, May, 1953

6. J. A. Olszewski and M. Lubarsa, "Structural Return Loss Phenomenon in Coaxial Cables, "Proceedings of the IEEE, Vol. 58, No. 7, July 1970, pp. 1036-1050

7. Packet Radio Temporary Note 5, Packet Radio--System Considerations, MRC, January 1, 1973

8. W. A. Rheinfelder, "CATV System Engineering", TAB Books, Blue Ridge Summit, Pa., 1970

9. L. G. Roberts, "Extensions of Packet Communication Technology to a Hand Held Personal Terminal", Spring Joint Computer Conference, Atlantic City, May 16, 1972, pp. 295-303

10. G. Rogeness, "Contributing Sources and Magnitudes of Envelope Delay in Cable Transmission System Components", Official Transcript 21st Annual National Cable Television Association Convention, Chicago, May 14-17, 1972.

11. M. Schwartz, W. R. Bennett and S. Stein, "Communication Systems and Techniques", McGraw-Hill, 1966.

12. J. Shekel, "CATV Reflections", TV Horizons, April, 1962

13. Sloan Commission Report on Cable Communications, "On the Cable: The Television of Abundance", McGraw-Hill, 1971

14. I. Switzer, "The Cable System as a Computer Network", in Proc. Symp. Computer-Communications Networks and Teletraffic (Polytechnic Institute of Brooklyn, N.Y.), April 1972

15. T. B. Ward, "Present and Possible CATV/Broadband-Communication Technology", Report ESL-R-469, June 7, 1971, Revised Feb. 3, 1972. A report prepared for the Sloan Commission on Cable Communications